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(54) Title: METHOD FOR TRANSMITTING A PILOT SIGNAL, AND A CELLULAR RADIO SYSTEM

(57) Abstract

The invention relates to a method for transmitting a pilot signal in a cellular radio system, which comprises in each cell at least one base station (100) communicating with mobile stations (102) located within its area, and which base stations transmit a pilot signal to the mobile stations, and which system comprises at least one base station (100) which transmits to the mobile stations (102) by using radiation patterns that change in time. In order to enable as efficient use of the pilot signal as possible, the system comprises at least one base station (100), which comprises means (606) for transmitting a pilot signal by using a rather narrow changing antenna beam, and means (606) for controlling the angle of the greatest gain of said antenna beam in such a way that the antenna beam sweeps the cell area.

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Method for transmitting a pilot signal, and a cellular
radio system

The invention relates to a method for
transmitting a pilot signal in a cellular radio system,
which comprises in each cell at least one base station
communicating with mobile stations located within its
area, and in which method the base stations transmit a
data signal in the downlink transmission direction by
using radiation patterns changing in time, and which
base stations transmit a pilot signal to the mobile
stations.

The present invention is applicable for use in
a data transmission system applying any multiple access
method, but especially in a cellular system utilizing
code division multiple access. Code division multiple
access (CDMA) is a multiple access method, which is
based on the spread spectrum technique and which has
been applied recently in cellular radio systems, in
addition to the prior FDMA and TDMA methods. CDMA has
several advantages over the prior methods, for example
spectral efficiency and the simplicity of frequency
planning. An example of a known CDMA system is disclosed
in the broadband cellular radio standard EIA/TIA IS-95.

In the CDMA method, the narrow-band data signal
of the user is multiplied to a relatively wide band by
a spreading code having a considerably broader band than
the data signal. In known test systems, bandwidths such
as 1.25 MHz, 10 MHz and 25 MHz have been used. In
connection with multiplying, the data signal spreads to
the entire band to be used. All users transmit by using
the same frequency band simultaneously. A separate
spreading code is used over each connection between a
base station and a mobile station, and the signals of
the different users can be distinguished from one

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another in the receivers on the basis of the spreading code of each user.

Matched filters provided in the receivers are synchronized with a desired signal, which they recognize on the basis of a spreading code. The data signal is restored in the receiver to the original band by multiplying it again by the same spreading code that was used during the transmission. Signals multiplied by some other spreading code do not correlate in an ideal case and are not restored to the narrow band. They appear thus as noise with respect to the desired signal. The spreading codes of the system are preferably selected in such a way that they are mutually orthogonal, i.e. they do not correlate with each other.

In a CDMA cellular radio system, it is possible to use a so-called pilot channel in the transmission direction of base station to subscriber equipments, i.e. in the downlink direction. A pilot channel is a signal which is transmitted with a specific spreading code and utilizing the same frequency band on which the actual traffic channels are situated, the pilot signal being distinguishable from them only on the basis of the spreading code. The pilot signal is a channel known and listened to by all subscriber equipments within the cell area, and it is used for example in power measurements and in the generation of a coherent phase reference. Each base station of the system transmits its own pilot signal on the basis of which the subscriber equipments can distinguish the transmissions of different base stations from each other.

US patent 5109390, which is incorporated herein by reference, and the aforementioned IS-95 standard disclose a prior art CDMA cellular system utilizing a separate pilot channel that is transmitted to the same coverage area with the data signals.

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In a typical mobile phone environment, the signals between a base station and a mobile station propagate along several paths between the transmitter and the receiver. This multipath propagation is mainly due to the reflections of the signal from the surrounding surfaces. Signals which have propagated along different paths arrive at the receiver at different times due to their different transmission delays. In the CDMA, the multipath propagation can be exploited in the reception of the signal in the same way as diversity. The receiver generally utilized in a CDMA system is a multibranch receiver structure where each branch is synchronized with a signal component which has propagated along an individual path. Each branch is an independent receiver element, the function of which is to compose and demodulate one received signal component. In a conventional CDMA receiver, the signals of the different receiver elements are combined advantageously, either coherently or incoherently, whereby a signal of good quality is achieved.

CDMA systems can also apply a soft handover wherein a mobile station may simultaneously communicate with several base stations by utilizing macrodiversity. The connection quality of the mobile station thus remains high during the handover and the user does not notice a break in the connection.

Interference caused by other connections in the desired connection thus appears in the receiver as noise that is evenly distributed. This is also true when a signal is examined in an angular domain according to the incoming directions of the signals detected in the receivers. The interference caused by the other connections in the desired connection thus also appears in the receiver as distributed in the angular domain,

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i.e. the interference is rather evenly distributed into the different incoming directions.

The capacity of the CDMA, which can be measured by means of spectral efficiency, has been further improved with sectorization. A cell is then divided into sectors of a desired size that are serviced by directional antennas. The mutual noise level caused by the mobile stations can thus be reduced significantly in the base station receiver. This is based on the fact that on average the interference is evenly distributed between the different incoming directions, the number of which can thus be reduced by means of sectorization. The sectorization can naturally be implemented in both transmission directions. The advantage provided in the capacity by the sectorization is proportional to the number of the sectors.

A sectorized cell may also utilize a softer handover wherein a mobile station performs a handover from one sector to another by communicating simultaneously with both sectors. Even though soft handover improves the connection quality and sectorization increases the system capacity, the movement of the mobile stations naturally leads to the stations performing several handovers from one sector to another. This loads the processing capacity of the base station controller. Several soft handovers also produce a situation where several mobile stations communicate simultaneously with more than one (usually two) sector, whereby the increased capacity provided by the sectorization is lost as a signal of a mobile station is audible in a wide sector.

The multiple access interference of the CDMA systems has also been reduced by means of different known multiple access interference cancellation (IC) methods and multi-user detection (MUD). These methods

are best suited for reducing the interference produced within the user's own cell, and the system capacity can thus be increased to about a double compared to a system implemented without interference cancellation. However, these methods do not provide a significant improvement in the size of the coverage area of the base station as compared to known technology, i.e. the cell size is not significantly altered with the application of these methods. Also, the IC/MUD techniques are complicated to realize, wherefore they have mainly been developed in the uplink direction.

Another method that has been developed is an SDMA (Space Division Multiple Access) method wherein the users are distinguished from one another on the basis of their location. This is performed in such a way that the beams of the receiver antennas at the base station are adjusted to the desired directions according to the location of the mobile stations. For this purpose, the system uses adaptive antenna groups, i.e. phased antennas, and the processing of the received signal, by means of which the mobile stations are tracked.

The use of the SDMA in connection with the CDMA provides several advantages over the prior methods, such as sectorization. If the sector beams in the sectorization are narrowed in order to increase the spectral efficiency, the number of the handovers to be performed from one sector to another also increases. This in turn increases too much the calculation capacity required in the base station controller.

In connection with the application of the SDMA, the background art is illustrated in A.F. Naguib, A. Paulraj: *Performance of CDMA Cellular Networks With Base-Station Antenna Arrays* (Proc. International Zürich Seminar on Digital Communications, pp. 87 - 100, Zürich, Switzerland, March 1994), which is incorporated herein

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by reference. In the SDMA a signal is thus received by means of an antenna group, and the received signal is shaped by means of digital signal processing in such a way that the directivity patterns of the antennas are suitable for the stages following the shaping in the receiver. In prior art arrangements, the received signal is shaped in order to maximize the signal-to-interference ratio of the desired signal. The received signal is thus shaped in such a way that the directivity pattern of the antenna group minimizes the interference caused by the other connections in the desired signal. In the arrangement according to the aforementioned reference, each detected signal component is subjected to individual beam shaping, i.e. the impulse response must be known before the shaping.

When data signals, i.e. traffic channels, are transmitted to mobile stations according to the SDMA principle by using changing beams, the use of the pilot signal will be problematic in the prior art arrangements. In known methods, the pilot signal has thus been transmitted continuously and together with the traffic channels so that the pilot could be used in the mobile stations for the identification of base stations and as an indicator of a need for handover. The conventional manner of transmitting a pilot signal restricts the cell coverage area, which could be larger in connection with changing antenna beams.

The deficiency in the antenna gain of a pilot signal transmitted with a known method must be compensated for with a higher transmit power or by increasing the processing gain in the subscriber terminals.

The purpose of the present invention is to realize a method for transmitting a pilot signal in connection with adaptive antenna beams in such a way

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that the pilot signal does not restrict the cell
coverage area. The purpose of the invention is to
implement the transmission of the pilot signal in such
a way that the mobile stations can use the pilot signal
in the identification of a base station and as an
indicator of a need for handover without the continuous
reception of the pilot in the subscriber equipments and
without a need to transmit the pilot signal with a
higher transmit power than the other signals.

This is achieved with a method of the type
described in the preamble, characterized in that a
rather narrow changing antenna beam is used in the
transmission of the pilot signal, and that the angle of
the greatest gain of the antenna beam is directed in
such a way that the antenna beam sweeps the cell area.

The invention also relates to a cellular radio
system comprising in each cell at least one base station
communicating with mobile stations located within its
area, and which base stations transmit a pilot signal
to the mobile stations, and which system comprises at
least one base station, which transmits to the mobile
stations by using radiation patterns that change in
time. The cellular radio system according to the
invention is characterized in that the system comprises
at least one base station, which comprises means for
transmitting a pilot signal by using a rather narrow
changing antenna beam, and means for controlling the
angle of the greatest gain of said antenna beam in such
a way that the antenna beam sweeps the cell area.

The method according to the invention helps
avoid the problems caused by the transmission of a pilot
signal in connection with adaptive antenna beams. A
pilot signal implemented in the manner according to the
invention does not restrict the cell size in the same
way as the previous methods, and the use of the antenna

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beams that change in time is as efficient as possible in the transmission of traffic channels.

In the arrangement of mobile antenna beams according to the invention, considerably better spectral efficiency is achieved when compared to the conventional cellular systems, including systems applying the CDMA method. The method increases both the number of the channels used by a factor of 10 to 100, and the size of the coverage area of the base station by a factor of 5 to 10. This is based on that fact that the effect of the interference caused by the other users decreases substantially in the method according to the invention, and since the CDMA is an interference-limited method, the number of the users can be increased. Secondly, the search according to the invention for advantageous signal components in the angle-of-arrival-time domain is technically advantageous to implement.

According to a preferred embodiment of the invention, the signal processing can be performed digitally on the base band, whereupon the antenna beams can be oriented directly to the desired directions by means of the phasing of the received signal.

In the arrangement according to the invention, the pilot signal can be transmitted in the cell by means of either one or several antenna beams in such a way that the antenna beams do not overlap.

In the following, the invention will be described in greater detail with reference to the examples according to the accompanying drawings, in which

Figure 1 illustrates the multipath propagation of a signal between a mobile station and a base station,

Figure 2a illustrates, on a time domain, the scattering caused by the multipath propagation of a signal,

Figure 2b illustrates, on the angle-of-arrival domain, the scattering caused by the multipath propagation of a signal,

Figure 3 illustrates a possibility of orienting the beam of the base station antennas towards the mobile station,

Figure 4 shows a possible implementation of an adaptive antenna group,

Figure 5 illustrates an example of the method according to the invention for transmitting a pilot channel,

Figure 6 is a block diagram illustrating a possible structure of a receiver according to the invention, and

Figure 7 is a block diagram illustrating an example of the structure of an individual channel element.

In the following, the method and receiver according to the invention will be described in greater detail using the CDMA system as an example, but not restricting the description thereto, however, since the invention is also applicable in connection with other multiple access methods, as will be evident for a person skilled in the art on the basis of the description below.

Figure 1 illustrates the typical multipath propagation of a transmitted signal in a cellular system. The figure shows a base station 100 and a mobile subscriber equipment 102 communicating with the base station. A characteristic feature of cellular radio systems is that the mobile stations are surrounded by surfaces that reflect and scatter radiowaves. Such surfaces may be for example buildings and walls formed by the nature, such as mountains and hills. Mobile stations typically transmit with an omnidirectional

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antenna pattern. The figure illustrates a few rays 112, 114, 116 originating from a mobile station. The surfaces 104, 108 situated close to the mobile station 102 reflect the transmitted signal, which therefore arrives
5   at the antenna of the base station 100 along several different paths, but the delay between the different signal components is rather small, however. The reflecting surfaces situated further from the mobile station, such as larger buildings and mountains, denoted
10   in this figure by numeral 106, produce signal components 114 which arrive at the base station 100 several, even dozens of microseconds later. There may also be obstacles 110 in the terrain that prevent a direct connection between the mobile station and the base
15   station.

Figure 2a illustrates, on the time domain, an example of a momentary delay of signal components caused by the multipath propagation of the signal at a base station receiver. The horizontal axis 200 of the
20   schematic figure shows the time and the vertical axis 202 shows the power of the received signal. In the example of Figure 2a, the base station receiver has detected three groups of signal components 204, 206, 208 which have arrived at the receiver at different times
25   and among which the component 208 is significantly more delayed than the others.

As the example of Figure 1 shows, the different signal components arrive not only at different times but also from different directions. It can thus be said that
30   the signal scatters not only in the time domain, but also in the angular domain, which can be described by the angle of arrival (AoA) of the signal. Figure 2b illustrates an example of a momentary scattering as a function of the angle of arrival, caused by the
35   multipath propagation of the signal, at the base station

receiver. The vertical axis 202 of Figure 2b shows the power of the received signal component, and the horizontal axis 210 shows the angle of arrival. In the example of Figure 2b, the signal components 212, 214 arrive from two directions.

In large cells, so-called macrocells, wherein the base station antennas are situated high, the signal components generally arrive at the antenna with only a few different angles of arrival, which are usually at the vicinity of the direct ray between the mobile station and the base station. In small microcells where the base station antennas are usually situated below the roofs of buildings, the angles of arrival of the signal components are found to show far greater dispersion, since in the same way as the mobile stations, the base stations are often surrounded by several reflecting surfaces situated near by.

The multipath propagation has been described above in the uplink transmission direction. It is naturally clear that a corresponding phenomenon also occurs in the opposite downlink direction. It can also be stated that the multipath routes are mainly symmetrical in both directions, since the scattering and reflection are not greatly dependent on the frequency. However, it should be noted that fast signal fadings are mutually independent in different transmission directions. Therefore, if the base station detects a signal component that has arrived from the mobile station at the angle of arrival of α_0, transmitting a signal with the same angle α_0 guides the signal in the direction of the mobile station, except for fast fadings.

On the basis of the above, it can be stated that the multipath propagating environment typical of cellular systems leads in the base stations to the

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reception of a signal which is distributed in time into several components that are delayed differently and in the angular domain into components arriving from several different directions. Both distribution profiles vary

5   in time since the subscriber equipments move, but the variation is rather slow, i.e. in the range of a few seconds, and the profiles can be synchronized with and they can be monitored.

The received signal components are thus
10   characterized by the multidimensionality of the type described above that is illustrated above with the time-angular domain, i.e. (α, τ) domain, and that can be utilized in the base station according to the invention for improving the detection of the signal to be
15   received. In the method according to the invention, the best signal components of the received signal are searched for in the multidimensional signal domain, the receiver being controlled by means of the components in such a way that the detected components can be
20   preferably combined and detected. The most simple standard for the signal quality can be the received power level, but also other standards can be used, for example the signal-to-noise ratio.

The receiver according to the invention
25   utilizes an adaptive antenna group, which is an antenna group consisting of several different elements. Figure 4 illustrates a possible implementation of an adaptive antenna group, which can be applied in connection with the first preferred embodiment of the invention. The
30   antenna group comprises L antenna elements 400, 402, 404, which may be for example omnidirectional antennas. Each antenna element is connected to radio-frequency parts 406, 408, 410, which convert the received signal into an intermediate frequency and sample the signal
35   into (I,Q) components according to known technology. The

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obtained complex samples are then multiplied by the corresponding complex weighting coefficients w_i, wherein $i = 1,...,L$, in multipliers 412, 414, 416. The samples 422, 424, 426 that have thus been multiplied are applied via an adder 418 to other parts of the receiver.

The complex weighting coefficients w_i are selected according to an algorithm, which is usually adaptive, in such a way that an antenna pattern of the desired shape is achieved. This manner of shaping the received signal can be called digital phasing of the signal, since it is performed on a signal digitized on the base band, but due to this shaping the received signal antenna gain can be oriented in the desired directions. An antenna group as such may comprise either directional or omnidirectional antenna elements. Phasing the signal obtained from the different antennas and combining the phased signals produces kind of virtual antenna beams into the desired directions. A corresponding treatment can also be performed on the signal to be transmitted, whereby a desired radiation pattern can be achieved.

Figure 3 illustrates how an antenna group consisting of an evenly spaced linear group comprising four elements 300, 302, 304, 306 produces a strong directed beam 310 with the angle of arrival of α towards a mobile station 308. A group of smaller side beams 312 to 316 are also formed. This directivity can thus be implemented with the signal phasing without the antennas as such being directional.

In the arrangement according to the invention, the multiple access interference of the receiver is reduced with antenna beams that are directed in the angular domain and that are produced by means of a new type of receiver applying time-angle diversity. In the arrangement according to the invention, the angles of

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arrival measured from the received signal can also be used in the transmission direction, whereby the connection quality is improved in both transmission directions.

In the following, the first preferred embodiment of the invention, which relates to applying the digital phasing of the received signal in the CDMA system, will be described first.

The receiver applying time-angle diversity used at the base station comprises digital receiver means that can monitor the received signal components in the two-dimensional (α, τ) domain and demodulate the desired signal components. Before the demodulation, the received digitized signal samples are subjected to phasing by means of which the antenna gain of the received signal is oriented in the desired signal incoming directions. In the preferred embodiment, the antenna beams produced by the phasing are beams having a predetermined shape that is determined by the weighting coefficients w_i and the antenna geometry. These coefficients can easily be calculated for each angle of the greatest gain if the shape of the antenna beam as such remains constant. Therefore, the phasing can be adjusted rapidly since it is only dependent on one parameter, i.e. the angle of arrival α.

In the method according to the invention, there is no need to apply known complicated techniques, such as MUSIC, for estimating the angle of arrival or adaptive algorithms, such as LMS and DMI. Even though these algorithms enable the calculation of the optimal beam shape for the signal to be received, so that the signal-to-noise ratio of the desired signal can be maximized by directing the zero points of the antenna pattern towards the sources of interference, this is not necessary in connection with the CDMA since, as

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described above, in the CDMA the interference signal is distributed to resemble noise without having any clear directions of interference source. Therefore, it is sufficient in an environment with evenly distributed interference that the angles of the greatest gain of the antenna beams having a predetermined shape are pointed in the directions from which the best signal components are received. This enables the implementation of a more simple receiver compared to the prior art.

In the method according to the invention, the receiver thus searches for the desired signal components in the (α, τ) domain. This is performed by cross-correlating the received spread-spectrum signal with the desired spreading code and by comparing the obtained measurement results with the threshold values given. The search can be understood as a sweep of an antenna beam over the given area, simultaneously performing the measurement of the channel impulse response and the collection of the signal energy of the terminal equipments received from each direction. The receiver thus detects the direction and code phase of the reception of the best signals and allocates a required number of demodulation means for synchronizing with and receiving these signal components. The received demodulated signal components can be preferably combined in the receiver. The search for the best signal components is performed continuously and the allocation of the demodulation means is changed, if necessary.

The receiver thus knows at all times the directions from which the best signal components from the mobile stations are received. This information can also be used in the base station equipment according to the invention in the downlink direction. This may be performed for example in such a manner that the controller of the transmitter-receiver informs the

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transmitter unit of the directions where significant signal components have been detected. The transmitter unit may phase the signal to be transmitted with the adaptive antenna group in such a way that the angles of the greatest gain of the antenna beams point in the desired directions. There may be one or more transmission beams and their number may also differ from the number of the receiver beams.

This method provides considerable interference cancellation also in the downlink direction. The antenna group used in the transmission may be the same as the antenna group used in the reception. It may also be a separate antenna group. The signal phasing is performed in the same way as during the reception with the weighting coefficients.

The arrangement according to the invention may use for example prior art mobile stations, which continuously perform measurements on the connection quality from the signal they have received from the base station. This information may comprise data concerning the number of the signal components the mobile station has received. The arrangement according to the invention may apply a method of utilizing the results of the connection quality measurements performed by the mobile station when the beams of the transmission antennas are directed in the downlink direction.

The mobile station transmits the measurement results it has collected to the base station. On the basis of the information received from the mobile station and the measurements it has performed itself, the base station may vary the number, shape or direction of the antenna beams it uses for the transmission of the signal intended to the mobile station. These changes can be implemented gradually, so that the mobile station can follow the changing signal.

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The base station may also use the connection quality information it has received from the mobile station for adjusting the transmit power of each antenna beam if the measurement results show that the aforementioned measures do not improve the signal quality in the mobile station.

One advantage of the method described above is that for example in a difficult fading situation the mobile station may transmit to the base station a request to change the parameters of the antenna beams used in the signal transmission, for example the direction, shape and number, whereby the quality of the signal received by the mobile station can be improved rapidly.

The prior art CDMA systems thus use a pilot signal that is transmitted by each base station and that is used in the identification of base stations, in power measurement and for enabling coherent reception in a mobile station. In known systems, a pilot signal that is a data-unmodulated spreading-coded signal is transmitted to the coverage area of the base station continuously in the same way as the actual traffic channels.

In the system according to the invention, a pilot signal is transmitted using a relatively narrow antenna beam, and the angle of the greatest gain of this antenna beam is directed in such a way that the antenna beam sweeps the cell area. The antenna beam is controlled by phasing the signal to be transmitted with the antenna group in the above-described manners. Thus the antenna beam comprising the pilot signal sweeps the cell like a lighthouse, and the transmission of a continuous pilot to the entire cell area can be avoided. The pilot can also be transmitted with several sweeping antenna beams, which are phased in such a way that they

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do not overlap. The base station informs the mobile stations on a control channel about the time when the pilot channel sweeps each area.

The transmission of the pilot channel can also be proportioned to the frame or multiframe structure of the base station, whereupon the pilot signal is transmitted in the same place of the frame structure or alternatively by sliding it over the frame structure every time with a certain phasing. In such a case, there is no need to separately inform the terminal equipments of the moment when the pilot signal is transmitted, but once a terminal equipment has received a pilot, it thereafter knows when the pilot will be transmitted.

The method is illustrated in the example of Figure 5 where the area of the base station is assumed to be circular while the base station is situated in the centre. However, the invention can also be applied for example in a sector-shaped coverage area. In the example of the figure, the base station transmits a pilot channel with a narrow antenna beam 550, which sweeps the cell area in the manner shown by the arrows 552, 554.

The transmission of the pilot channel can also be implemented in such a way that the channel is transmitted with several narrow beams simultaneously. In the case of Figure 5, the base station could transmit the pilot channel for example with the beams 550, 556, 558, each of which rotates in the same direction with the same angular speed, whereby they do not overlap.

Due to reflections occurring over the radio path, the radiation pattern of an antenna beam is not accurately specified, but in practice the antenna beam is substantially narrower than the total area of the cell.

Since the pilot signal is thus not continuously audible everywhere in the cell, the measurement of the

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pilot signal in the mobile stations has to be implemented in such a way that a momentary inaudibility of the pilot signal does not immediately produce a handover message. The mobile station should thus know which base station uses the technique of sweeping to transmit a pilot signal and the time when each pilot signal sweeps the location area of the mobile station. This is realized in the arrangement according to the invention in such a way that the base station forwards, on a general control channel, information on how often or at which intervals the beam comprising the pilot channel travels over the cell. This information, which will be denoted below with the parameter t_period, depends on the speed of rotation of the antenna beam and on the number of the antenna beams used. Since a mobile station must regularly measure the pilot signals of the surrounding base stations while maintaining active communication with the base station, it should know the t_period parameters of all the neighbouring base stations.

The mobile stations also monitor the pilot channels of the base stations other than the one with which they communicate. In order to avoid a situation where a mobile station should measure several pilot signals simultaneously, the t_period parameters used by adjacent base stations can be defined differently. Another alternative is to divide the measuring time among several pilot channels. The rotation of the pilot channel beams of adjacent base stations can also be synchronized by using suitable phasing so that no overlapping occurs. This can be taken into account in network planning. If the network is synchronized, the aforementioned t_period is the same for every base station.

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In the following, the structure of a base station equipment according to the first embodiment used in the cellular radio system according to the invention will be described. Figure 6 is a block diagram
5   illustrating the structure of equipment according to the invention. The equipment comprises an antenna group 500 consisting of L separate antenna elements. The antenna group may be linear, planar (two-dimensional) or omnidirectional. The antenna group 500 receives a
10   multipath-propagated signal that is delayed in different ways from several different directions from each mobile station with each of the L elements, performs the preamplification, converts the signal into an intermediate frequency and digitizes all the L signals.
15   The obtained L digital complex I,Q samples 514 are supplied into an input of channel elements 504, 506, 508.

Each active mobile station communicating with the base station is serviced by one channel element,
20   which performs digital signal processing both on the received signal and on the signal to be transmitted, as will be described in greater detail below. Each channel element comprises a (α, τ) receiver and a corresponding transmitter. The digital shaping functions of the
25   antenna beam, realized by means of the signal phasing, are performed in a channel element both in the transmission direction and in the direction of reception.

In the direction of reception, a channel
30   element filters the signal on the angle-space domain, demodulates the received signal components and combines them in a diversity combiner and in the end decodes the signal that has been received from the mobile station and that has been combined. The obtained user data bits

are supplied further to a baseband unit 510, which forwards them to other parts of the network.

In the transmission direction, the user data bits arrive from the other parts of the network to the baseband unit 510, which forwards them to the correct channel element 504 to 508 where they are encoded, modulated by a spreading code and subjected to the phasing of the signal to be transmitted, the phasing determining the directions of the antenna beams to be transmitted. The obtained L signals are supplied to each of the L elements of the antenna group 502. In practice, the reception and transmission antenna groups 500, 502 may be either separate or implemented by means of the same physical antenna group where the directions of transmission and reception are separated with suitable duplex filtration.

In the transmission antenna group 502, the signals that have arrived from each channel element and that are intended to each antenna element are converted into analog form, transferred to a radio frequency and transmitted via the antenna elements.

In the arrangement according to the invention, the transmission and reception antenna groups may naturally comprise a different number of antenna elements, even though the description above discloses the same number L of elements in each group for the sake of simplicity. The figure also shows a control block 512, which controls the operation of the different units of the equipment, such as the allocation of the channel units to different connections according to the messages from the base station controller.

Figure 7 is a block diagram illustrating the structure of a channel element in the equipment according to the first embodiment of the invention. The channel element comprises one or several digital

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receiver units 600, 602 two of which are shown in the
figure, one or several searcher units 604 one of which
is shown in the figure, a diversity combiner 608 the
input of which comprises a signal from the receiver
units, a decoder 610 to the input of which a signal that
is visible at the output of the diversity combiner 608
is connected, and control means 612. The L digital
complex I,Q samples 514 arriving from the antenna group
are supplied to the input of all the digital receiver
units 600, 602 and searcher units 604. If the
arrangement according to the invention is applied in a
transmitter-receiver, the transmitter-receiver according
to the invention also comprises an encoder 614 and a
digital transmission unit 606.

The operation of the digital searcher unit 604
is examined first with reference to Figure 7. In the
same way as in a conventional rake receiver, the
function of the searcher unit is to search for the
desired signal components from the received signal. In
the arrangement according to the invention, a new type
of searcher unit continuously monitors the received
signal in the (α, τ) domain and searches for useful
signal components and gives their parameters, i.e. the
angle of arrival (AoA) and the delay profile, to the
control means 612, which in turn allocate a required
number of receiver units for demodulating the best
components. The receiver according to the invention can
naturally also be implemented in such a way that a
channel element does not comprise separate control means
612, but the searcher unit 604 forwards the information
concerning the signal components to be monitored
directly to the receiver branches 600, 602.

The searcher unit comprises means 634 for
phasing the signal supplied from the radio-frequency
parts of the antenna group, and means 636 for detecting

whether the signal obtained from the output of the phasing means 634 comprises a signal component received with the given delay and for measuring the quality of this signal component. The searcher unit further comprises means 638 for controlling the aforementioned phasing means 634 and the measuring means 636 in such a way that the incoming directions and delays of the received signal can be measured.

The means 634 for phasing the signal supplied from the radio-frequency parts of the antenna group can be implemented for example with equipment of the type described above and shown in Figure 4, the equipment comprising the multiplication of the signal with complex coefficients w_i ($i=1,\ldots,L$) by means of which it is possible to determine the angle of arrival of the signal that is visible amplified in the output signal of the phasing means. Each combination of the coefficients corresponds to a certain combination of antenna beams, as described above. The phasing means (634) are controlled by the means 638 so that all the essential incoming directions of the signal can be examined.

The output of the phasing means thus shows a signal that corresponds to the signal received from a given direction on the basis of the control of the means 638. The measuring means 636 perform a measurement with different delays on a signal visible at the output of the phasing means, the purpose of the measurement being to detect the signal components that have different delays. The delay to be measured each time is set with the aforementioned means 638. In the measuring means, the signal situated at the input of the means is subjected to despreading, measurement of the complex signal energy and squaring of the energy for example over the coherence time of the channel, and comparison of the obtained measurement result ·with the given

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threshold value. The parameters of the measured signal
components having a strength exceeding the given
threshold value, i.e. the angle of arrival, delay and
power, are provided to the control means 612 of the
channel element.

The means 638 thus control the operation of the
phasing means 634 and the measuring means. The means 638
correspond to a synchronization loop provided in the
searcher branch of a conventional rake receiver, even
though in the arrangement according to the invention the
means operate in a new manner. The search for the
desired signal components from the (α, τ) domain can be
implemented in many ways under the control of the means
638. As stated above, the measurement of the signal
power can be replaced with some other measurement of the
signal quality.

The digitized signal received by the antenna
group can be phased in the phasing means 634 step by
step in such a way that the direction angle of the
greatest gain is changed with given angle intervals.
From among the possible incoming directions, one selects
a representative group of angles of arrival α_j which are
situated at desired angle intervals from one another,
and each incoming direction is subjected to several
energy measurements at different delay values, whereby
a delay profile τ_k is obtained for the incoming
directions.

Another way is to direct the measuring means
636 to first measure the delay profile τ_k of the
received signal for example with a non-directional
antenna pattern. The possible delays with which signal
components are received are thus detected. The phasing
means 634 are thereafter directed to sweep the different
direction angles with a narrow directional beam, and the
measuring means are simultaneously guided to measure

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with the aforementioned delay values detected in the first measurement. The incoming directions α_j of the components that have arrived with different delays are thus obtained.

The parameters of the detected signal components are thus given to the control means 612 of the channel element. The control means allocate the receiver elements 600, 602 to receive and demodulate the best detected signal components by informing the receiver element of the incoming direction and delay of the signal component. As stated above, the receiver elements can also be controlled directly by the searcher unit 604 without separate control means.

The operation of the digital receiver unit 600, 602 will be examined next with reference to Figure 7. In the same way as in a conventional rake receiver, the function of the receiver unit is to receive and demodulate a given signal component. Assume that the control means 612 of the channel element have allocated a receiver unit to receive a particular signal component the parameters of which are the angle of arrival α_j and the delay τ_k.

The receiver unit 600, 602 comprises monitoring means 624, 632 to which the control means 612 of the channel element forward the information about the phase and incoming direction of the signal component to be monitored. The monitoring means control the first phasing means of the receiver unit the input of which is the digitized signal obtained from the antenna group. The phasing means 618, 626 have a similar structure as the phasing means 634 provided in the searcher unit. On the basis of the information that concerns the angle of arrival α_j and that is received from the control unit, the monitoring means set the complex weighting coefficients w_i (i=1,..,L) in such a way that a signal

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arriving from the desired incoming direction is visible at the output of the phasing means. This can thus be understood as a receiver antenna beam pointing in the desired direction and having a predetermined shape.

The receiver unit 600, 602 further comprises demodulation means 620, 628 the input of which comprises a signal obtained from the phasing means 618, 626. The monitoring means 624, 632 guide the demodulation means to synchronize with a signal component arriving with a given delay τ_k. In the demodulation means, the signal is subjected to despreading and demodulation according to known technology using the given τ_k as the code phase. The obtained symbols are supplied to the other parts of the channel element together with the delay data.

The receiver unit 600, 602 further comprises second phasing means 622, 630 the input of which comprises a digitized signal obtained from the antenna group. The output signal of the second phasing means is supplied to the monitoring means 624, 632. The monitoring means control the operation of the second phasing means by measuring with the means the environment of the current parameters (α_j, τ_k) of the signal component allocated to the receiver in order to detect possible changes in the incoming direction and delay of the received signal component. For this purpose, the second phasing means comprise complex coefficients similar to the first phasing means for phasing the signal, and means similar to the measuring means 636 situated in the searcher unit for measuring the impulse response. If the monitoring means detect, by means of the second phasing means, changes in the incoming direction α_j or delay τ_k of the desired signal component, they update this data to the first phasing means and to the demodulation means.

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The prior art discloses several manners in which the monitoring means 624, 632 can be implemented in a spread spectrum system, for example Early-Late gates that can be used in the arrangement according to the invention. These circuits estimate the code timing error by performing two energy measurements with the given time difference $\Delta\tau$, which is typically a fraction of the chip time of the spreading code in the environment of the current set point τ_k. The energy measurements are performed with the measuring means of the second phasing means 622, 630, which provide the correction data required by the nominal set point τ_k as the delay changes.

Correspondingly, changes in the angle of arrival α_j of the signal can be monitored by means of the second phasing means. It is for example possible to perform, with the given delay τ_k, two or more energy measurements with antenna beams which have been deflected by an angle $\Delta\alpha$ in both directions from the current angle of arrival α_j by means of phasing. The degree of the deflection $\Delta\alpha$ used is typically a fraction of the width of the antenna beam.

The monitoring means 624, 632 thus control the energy measurements performed by the second phasing means 622, 630, so that a signal could be received with the greatest possible energy at all times. The monitoring means update the data about the changed parameters (α_j, τ_k) to the first phasing means, to the demodulation means and also to the control means 612 of the channel element, so that the data could be used in the transmission direction, if required.

The above-described maximization of the received signal can be compared with the receiver antenna diversity used in conventional systems, wherein a signal is received with two or more antennas situated

from each other at a distance having the length of several wavelengths of the received signal. In the receiver according to the invention, if a signal received with the angle of arrival α_j is caught in a deep and long fading situation, the fading can probably be eliminated by changing the angle of the receiver beam by a small angle $\Delta\alpha$. There is thus no need for two separate antennas situated at a given distance from each other.

The operation of the diversity combiner 608 and the decoder 610 of the channel element is similar as in the prior art diversity receivers. The combiner 608 combines the symbol sequences arriving from the different receiver elements by taking into account and compensating for their different delays τ_k and possibly by weighting the different symbol sequences according to their signal-to-noise ratios in order to obtain maximum ratio combination. The combined symbol sequence thus obtained is supplied to the decoder 610, which decodes the symbols to user data bits, usually performing the deinterleaving first. The CDMA applications generally use a strong convolutional coding for which the best method of detection is the Viterbi algorithm providing a soft decision.

It is clear that the above-described channel element can also be used for monitoring and receiving an access channel. The antenna beams used in the direction of reception have then wider antenna patterns, i.e. they can be for example 120° wide, since the exact location of the mobile stations transmitting call-set-up messages is not known.

The operation of the digital transmission unit 606 will be examined next with reference to Figure 7. The user data bits are first supplied to the encoder 614, which encodes the bits typically with a

convolutional code and performs interleaving on the encoded symbols. The obtained interleaved symbols are applied to a spread spectrum modulator 642, which performs conventional modulation. All the above-described functions can be performed according to known technology.

In the present invention, the transmission unit comprises means 644, 640, however, for controlling and phasing digitally the signal to be transmitted in response to the received signal. In the transmission unit according to the invention, the means 644 for adjusting the transmission beam receive from the control means 612 of the channel element information in their input about the incoming directions used in the different receiver units 600, 602 for receiving a signal from the mobile station. The control means 612 may also report the other incoming directions of the signal detected by the searcher unit 604, but not all the directions are necessarily used in the reception of the signal.

The means 644 of the transmission unit for adjusting the transmission beam control the phasing means 640, which calculate from predetermined beam-forming functions JxL a complex weighting coefficient w_{ij} (i=1,...L; j=1,...,J) which produces J antenna beams by means of L antenna elements. In addition to the direction and number of the antenna beams, the means 644 control the phasing means 640 by indicating the transmit power that is to be used with each beam and that the means 644 obtain from the control means 612 of the channel element.

The structure of the phasing means 640 may be similar to the phasing means 618, 626, 634 described above in the direction of reception. In the phasing means, the digitized (I,Q) samples of the outbound

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signal supplied from the modulation means 642 are thus multiplied by L complex weighting coefficients where L is the number of the antenna elements, as follows:

$$v_i = \sum_{j=1}^{J} g_j w_{ij}, \quad i = 1, \ldots, L$$

whereby L complex sample sequences are obtained for the antenna group. The complex multiplication also uses a real scaling factor g_j $(j=1,\ldots,J)$, which is obtained from the adjusting means 644 and which can be used for the independent power adjustment of each antenna beam. The adjusting means 644 also indicate the frequency to be used, so that the weighting coefficients w_{ij} can be set correctly.

The arrangement according to the invention can also use special beam control bits that a mobile station generates on the basis of the signal it has received and that it adds to the signal it transmits to the base station. The receiver according to the invention comprises means 616 for demultiplexing and detecting these beam control bits from the received signal. The detection should be performed already before the decoder 610 in order to avoid delays. The beam control bits are forwarded to the adjusting means 644 of the transmission unit.

The means 644 for adjusting the transmission beam control the phasing means 640 on the basis of the information obtained from the control means of the channel element and the beam control bits transmitted by the mobile station. The adjustment can be performed in many ways by modifying the parameters α_j and g_j $(j=1,\ldots,J)$ in different ways. For example the transmit power used with some antenna beams can be independently adjusted, or the direction angle α_j of some antenna

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beams can be changed by a given angle $\Delta\alpha$, or the number of the antenna beams used can be altered. With these measures it is possible to compensate for the deteriorations of signal quality, such as fadings, occurring over the radio path.

In the arrangement according to the invention, the adjusting means 644 of the transmission unit 606 can deflect the direction of one or several of the used antenna beams by small degrees $\Delta\alpha$ in the environment of the given direction angle α_j. Due to such deflection, it is possible to reduce the likelihood that the mobile station would be in a deep fading for a long time. Since the direction angle of an antenna beam continuously vibrates around a nominal direction angle α_j, a signal that has propagated over the radio path does not continuously use the same route. This method can be considered a new type of antenna diversity in the downlink direction.

In the arrangement according to the invention, the adjusting means 644 control the phasing means 640 in such a way that with the suitable adjustment of the weighting coefficients w_{ij} (i=1,...,L; j=1,...,J) and the factors g_j (j=1,...,J), one or several signals having a rather narrow antenna beam are obtained from the transmitting antenna group, the angle of the greatest gain of the signal sweeping the cell area continuously. The antenna pattern thus obtained is used for the transmission of the pilot signal. The adjusting means 644 may control the phasing means 640 also in such a way that the pilot channel is transmitted with several rotating narrow beams simultaneously.

Even though the invention is described above with reference to the example according to the accompanying drawings, it is clear that the invention is not restricted thereto, but it can be modified in

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many ways within the scope of the inventive idea
disclosed in the appended claims.

The method according to the invention can also
be implemented in the uplink transmission direction. The
mobile station then transmits a long transmission burst
on the access channel, and the base station uses in the
reception a rotating antenna beam, which detects this
transmission. With this arrangement the number of the
channel elements needed on the access channel can be
reduced at the base station. By means of the
arrangement, the same antenna gain can be used on the
access channel as on the traffic channel. This results
in the fact that the terminal equipment does not have
to use a high transmit power when transmitting a call
set-up message, whereby the interference caused in the
other connections is reduced.

The alignment of the antenna beams can be used
for example in both the vertical and the horizontal
direction, whereby the above-described (α, τ) domain can
be understood as an (α, β, τ) domain, wherein α is the
vertical angle, β is the horizontal angle and τ is the
delay.

One possibility is to utilize coherent,
incoherent or differentially coherent modulation and
demodulation methods in the channel elements. For
example in order to enable coherent demodulation in a
mobile station, the base station may include known
reference symbols in each antenna beam as a phase
reference.

One alternative embodiment of the invention
includes positioning the digital phasing means 618 to
634 of the channel elements in one common phasing means
block, which services all channel elements.

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Claims:

1. A method for transmitting a pilot signal in
a cellular radio system, which comprises in each cell
at least one base station (100) communicating with
mobile stations (102) located within its area, and in
which method

the base stations transmit a data signal in the
downlink transmission direction by using radiation
patterns changing in time, and which

base stations transmit a pilot signal to the
mobile stations, c h a r a c t e r i z e d in that

a rather narrow changing antenna beam is used
in the transmission of the pilot signal, and that

the angle of the greatest gain of the antenna
beam is directed in such a way that the antenna beam
sweeps the cell area.

2. A method according to claim 1, c h a r a c-
t e r i z e d in that the same pilot signal is
transmitted with more than one antenna beam.

3. A method according to claim 2, c h a r a c-
t e r i z e d in that the angles of the greatest gain
of the antenna beams point in different directions at
each moment.

4. A method according to claim 1, c h a r a c-
t e r i z e d in that the base station transmits to the
mobile stations located within its area information
about the time when the antenna beam comprising the
pilot channel sweeps any sector of the coverage area.

5. A method according to claim 1, c h a r a c-
t e r i z e d in that

the base station receives a signal from a
mobile station by means of an antenna group (500)
consisting of several elements, and that

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the incoming directions and delays of the signal components are searched for from the received signal, and that

when a data signal is transmitted from the base station to the mobile station by means of the antenna group (500, 502) consisting of several elements, the formation of the radiation pattern used is controlled on the basis of said measurement.

6. A method according to claim 1, c h a r a c-t e r i z e d in that the antenna beams transmitting the pilot signal of the adjacent base stations is controlled in such a way that the beams do not overlap at any moment.

7. A method according to claim 1, c h a r a c-t e r i z e d in that the control of the antenna beams is synchronized with the general timing of the system.

8. A cellular radio system comprising

in each cell at least one base station (100) communicating with mobile stations (102) located within its area,

and which base stations transmit a pilot signal to the mobile stations,

and which system comprises at least one base station (100), which transmits to the mobile stations (102) by using radiation patterns that change in time, c h a r a c t e r i z e d in that

the system comprises at least one base station (100), which comprises means (606) for transmitting a pilot signal by using a rather narrow changing antenna beam, and

means (606) for controlling the angle of the greatest gain of said antenna beam in such a way that the antenna beam sweeps the cell area.

9. A cellular radio system according to claim 8, c h a r a c t e r i z e d in that the base station

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(100) comprises at least one antenna group (500, 502) consisting of several elements, a group of radio-frequency units (500) connected to the antenna group, one or several channel units (504-508) which are functionally connected to the radio-frequency parts (500) and which channel unit comprises means (606) for phasing the signal to be transmitted with the antenna group (502), so that the gain obtained from the antenna group is greatest in the desired direction.

10. A cellular radio system according to claim 8, c h a r a c t e r i z e d in that the base station comprises means (606) for transmitting to the mobile stations information about the time when the antenna beam comprising the pilot channel sweeps any sector of the coverage area.
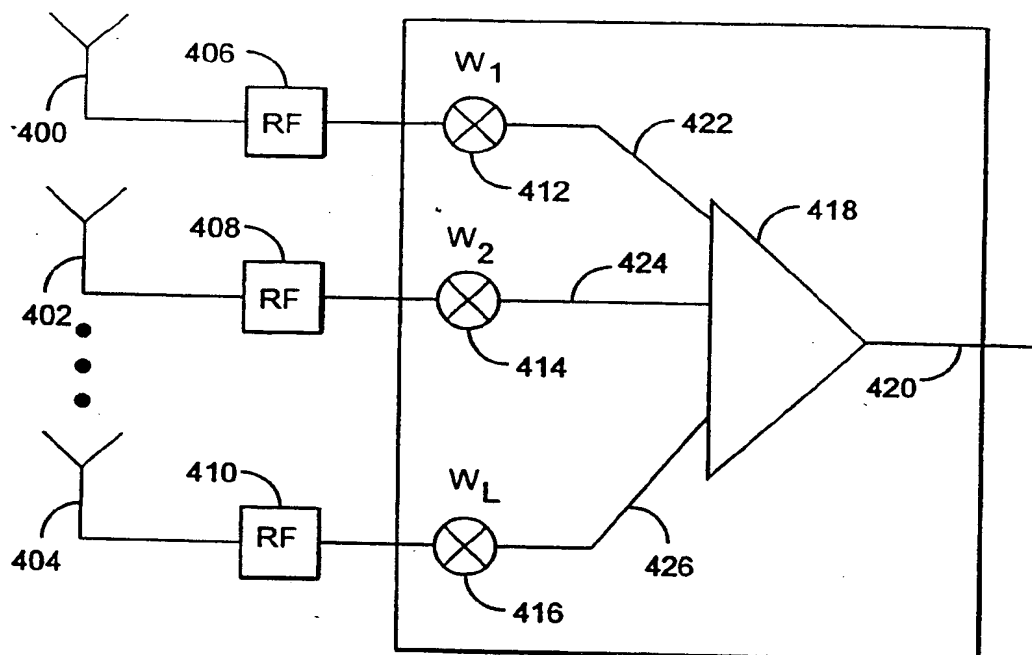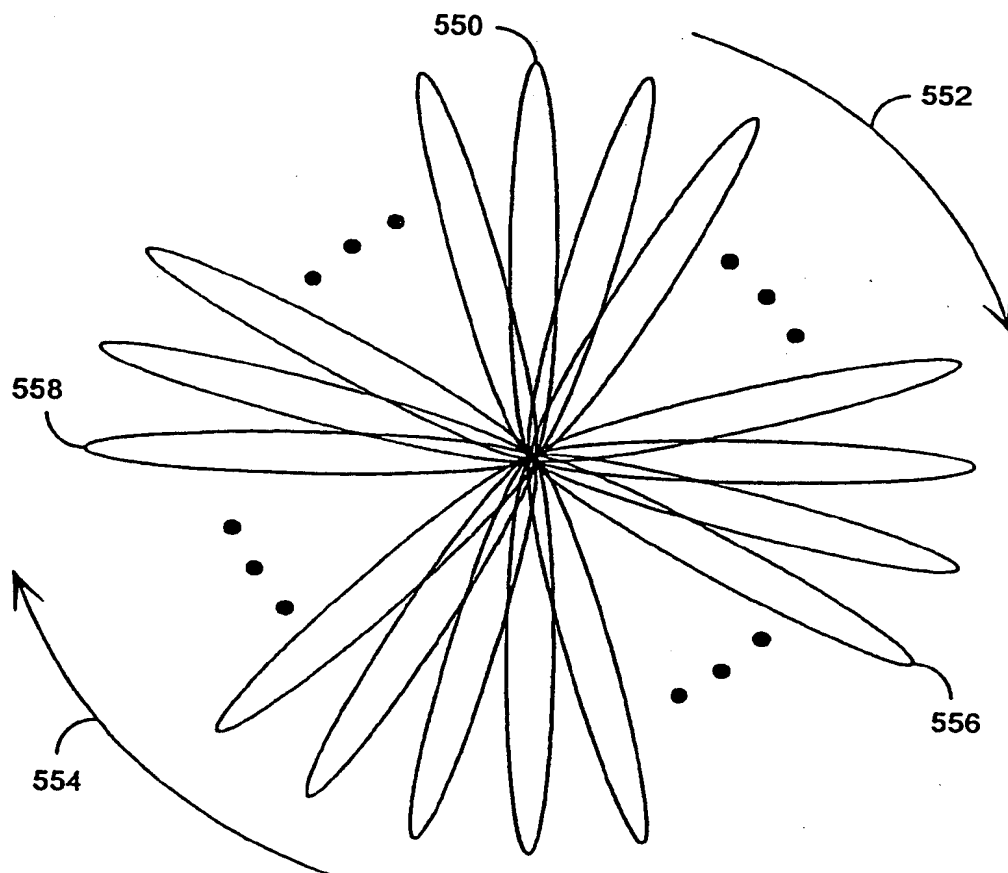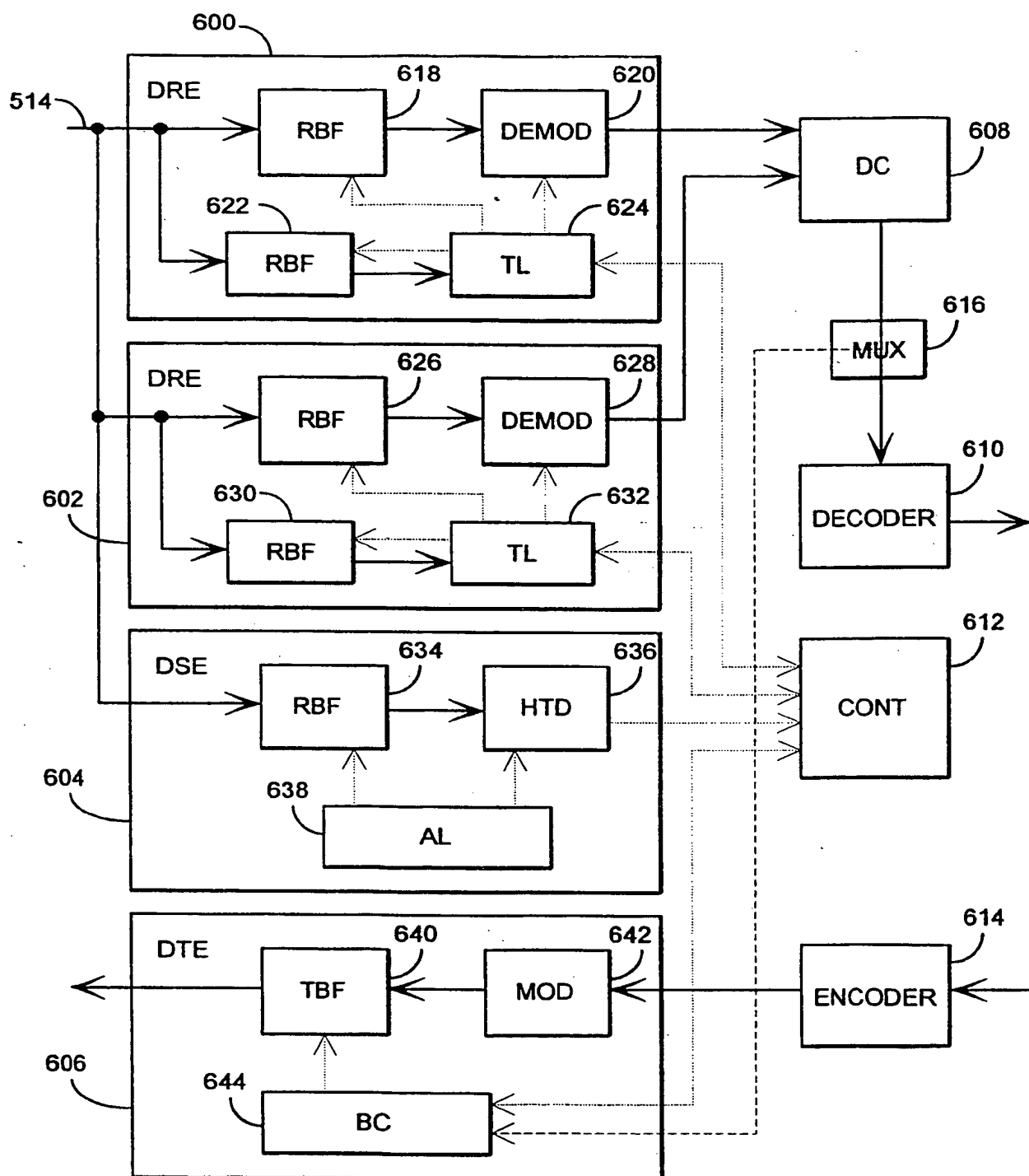
1 / 4

Fig. 1

Fig. 2a

Fig. 2b

Fig. 3

Fig. 6
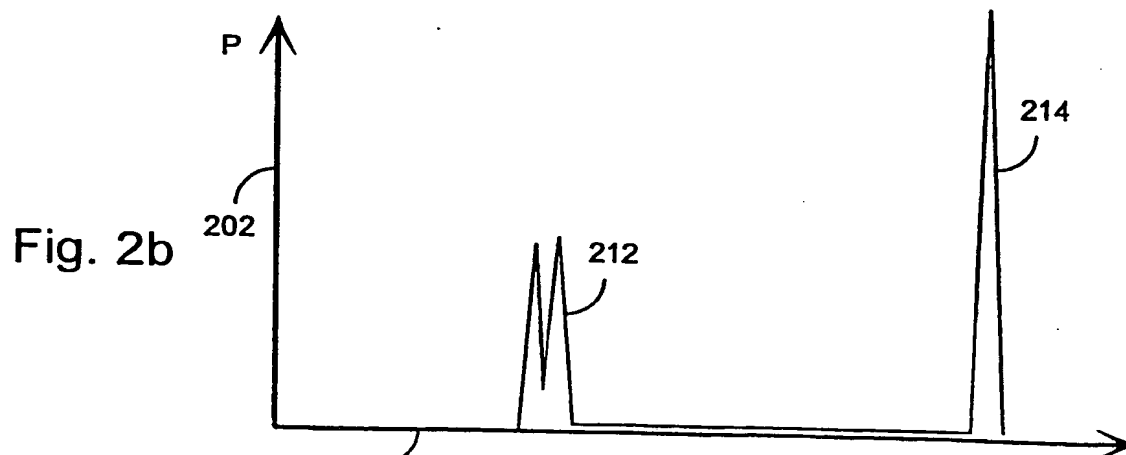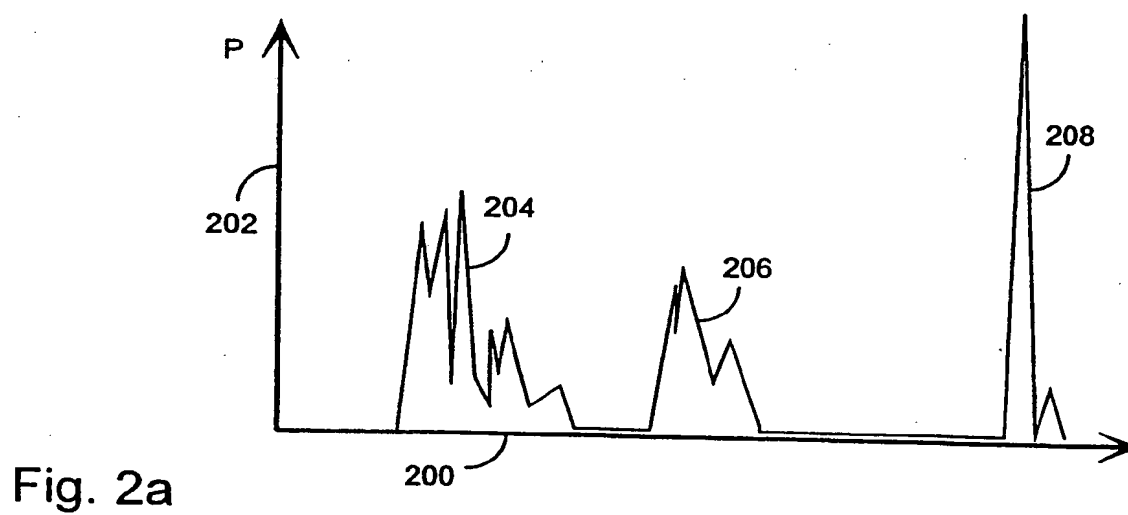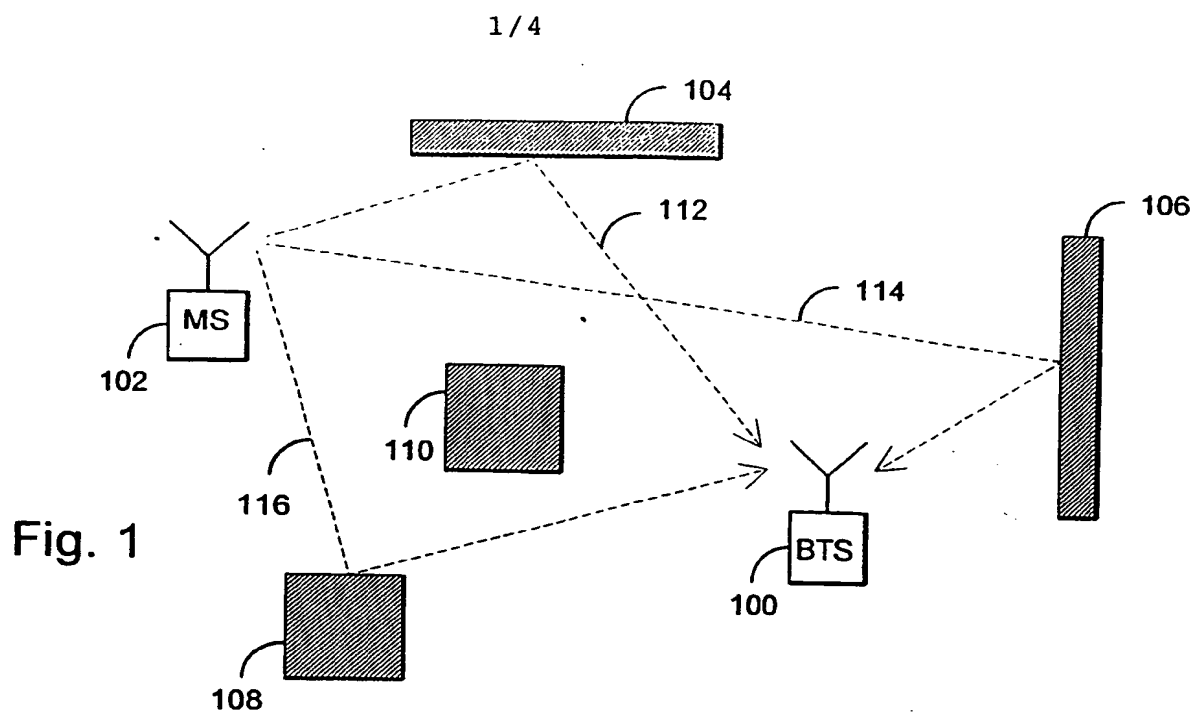
Fig. 4

Fig. 5

Fig. 7

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04B 1/76, H04B 7/26
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04B, H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EDOC, JAPIO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 9509490 A1 (TELEFONAKTIEBOLAGET LM ERICSSON), 6 April 1995 (06.04.95), figure 2(a)-2(b), abstract	1-10
A	EP 0647979 A2 (NORTHERN TELECOM LIMITED), 12 April 1995 (12.04.95), column 14, line 35 - line 57, figures 15a-15c	1-10
A	US 5109390 A (KLEIN S. GILHOUSEN ET AL), 28 April 1992 (28.04.92), column 6, line 1 - line 50	1-10

[X] Further documents are listed in the continuation of Box C.   [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 August 1996	2 9 -08- 1996

Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM	Göran Magnusson

INTERNATIONAL SEARCH REPORT

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5267261 A (ROBERT D. BLAKENEY, II ET AL), 30 November 1993 (30.11.93), abstract	1-10

International application No.
PCT/FI 96/00291

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO-A1- 9509490	06/04/95	AU-A- 7793594	18/04/95
		CN-A- 1116024	31/01/96
		EP-A- 0671085	13/09/95
		FI-A- 952582	26/05/95
EP-A2- 0647979	12/04/95	EP-A- 0647978	12/04/95
		EP-A- 0647980	12/04/95
		EP-A- 0647981	12/04/95
		EP-A- 0647982	12/04/95
		EP-A- 0647983	12/04/95
		EP-A- 0639035	15/02/95
		GB-A- 2281007	15/02/95
		JP-A- 7079476	20/03/95
		GB-A- 2281008	15/02/95
		GB-A- 2281010	15/02/95
		GB-A- 2281009	15/02/95
		GB-A- 2281011	15/02/95
		GB-A- 2281175	22/02/95
		GB-A- 2281176	22/02/95
		GB-A- 2281012	15/02/95
US-A- 5109390	28/04/92	AU-B- 649987	09/06/94
		AU-A- 6874891	31/05/91
		CA-A- 2072876	08/05/91
		CN-A- 1061311	20/05/92
		EP-A- 0500761	02/09/92
		IL-A- 96220	12/04/94
		JP-T- 4502844	21/05/92
		WO-A- 9107036	16/05/91
US-A- 5267261	30/11/93	NONE	